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HIGH VOLTAGE CABLE SPLICING AND CABLE TERMINATION TECHNIQUES

By

David E. Weems

August 1976

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The splicing and termination of underground electrical distribution cable requires that the integrity of cable conductor and insulation be maintained throughout its length. A large number of commercial cable splice and termination kits are available which are claimed to fulfill these requirements. The Civil Engineering Laboratory (CEL) was requested to investigate the suitability of these kits for use at Naval shore facilities. Of special interest were the slip-on cable splice and cable termination for solid dielectric insulated cable. These slip-on devices proved to be the easiest and fastest to install with

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INTRODUCTION

Electrical distribution systems at Naval shore facilities consist of long lengths of conductors operating at voltages in excess of 600 volts. Because of the length of the conductors required, it is necessary to join or splice conductors together. In the case of overhead transmission lines it is a simple task to install the conductors, since insulation of the conductors is not required. With underground distribution systems, splicing conductors is complicated by the requirement for insulation around the conductor to prevent electrical contact with the earth. When the conductors are spliced the insulation and shields must also be joined.

To splice electrical power cable, insulation material is wrapped around the joined conductor. With the development of solid dielectric insulated cables came the premolded or ''slip-on'' splice kit, a large number of which are commercially available. The manufacturers claim that the kits provide the same or improved splice quality when compared to the hand-wrapped type, with less training and experience required of the installation personnel.

The objective of testing these splice kits is to evaluate their electrical properties, safety, durability, reproducibility, ease, and time and cost of installation.

BACKGROUND

Electrical power is normally distributed by copper or aluminum conductors. In overhead distribution systems where conductor separation from ground and each other can be maintained, insulation is not necessary. This is not the case where the electrical distribution system is underground or is accessible to personnel.

Oil-impregnated paper, varnish cambric, or a solid dielectric material is used to insulate high voltage power cable. The first two types of insulation require a lead sheath to protect the insulation from the environment. Because of the lead sheath, splicing and termination of cables with these types of insulation must be performed by a highly skilled cable splicer.

The solid dielectric insulated cables have a rubber or rubber-like material covering the conductor to provide both insulation and environmental protection. Splicing of this type of cable requires use of insulation material to build up the insulation over the joined conductors. The finished result must be electrically equivalent to the original cable insulation. Several different types of termination and splice kits are available to simplify this procedure. They include: kits that provide tape and directions, kits that have precut tape, and premolded slip-on cable splices.

Naval shore facilities have experienced operational failures with high voltage cable splices now used in underground electrical power distribution systems. These failures were caused in most cases by moisture penetration in underground distribution systems subject to high water tables or flooding from surface drainage.

As a result of these failures, the Civil Engineering Laboratory (CEL) was requested to evaluate the state-of-the-art high voltage cable splicing and termination techniques and materials.

INDUSTRY SURVEY

The industry was surveyed to determine the types of electrical power cables used for underground electrical distribution and the method of splicing each type. The survey included contacting four of the electrical power cable manufacturers, six of the cable splice material manufacturers, three electrical utility companies, and several Naval shore facilities.

Cables Used for High Voltage Underground Distribution

High voltage cables currently manufactured for underground distribution fall into one of two types: paper-insulated lead-covered (PILC) cable and solid dielectric insulated cable.

The PILC cable consists of a copper conductor insulated with oil-impregnated paper. Due to the presence of the oil and the deteriorative effect of water on the insulation properties, a lead covering is added over the insulation. This lead covering holds the oil in and protects the insulation from the environment.

PILC cable is the oldest type of electrical power cable. The popularity of this type of cable has dropped since the 1940's when solid dielectric insulated cable was introduced. Electrical utility companies, such as Southern California Edison, are currently installing PILC cable only in locations where space limitations require replacement of existing cable with PILC cable instead of solid dielectric insulated cable.

The Navy still uses a large amount of PILC cable. For example, Mare Island Naval Shipyard's underground electrical distribution system is approximately 90% PILC cable.

The second type of high voltage underground cable is the solid dielectric insulated cable. This type of cable is normally constructed with five parts: the conductor, the conductor shield, the insulation, the insulation shield, and the outer conductor (Figure 1).

The insulation material is a synthetic insulating rubber produced from oil. Two of the most popular solid dielectric insulations currently used are high-molecular-weight polyethylene (EP) and cross-linked polyethylene (XLPE). The EP insulation is rated for $75^{o}C$ a maximum temperature, and the XLPE insulation is rated for $90^{o}C$ maximum temperature. These insulation materials provide the conductor with protection from the environment,' thereby eliminating requirement for a lead covering. An outer jacket is added on many cables to provide environmental protection for the outer conductor.

The conductor used in the past for electrical power cables has been copper; however, a large number of the cables currently being installed have lower cost aluminum conductors. The use of aluminum instead of copper can reduce the material cost up to 50%.

The cost of installing PILC with copper conductors is compared to the cost of installing XLPE cable with aluminum conductors in Table 1.

The manufacturers design the shields on solid dielectric insulated cables to confine the electric field to the insulation between the shields. The shields are a semiconducting material; therefore, they maintain a constant potential at the boundaries of the insulations. During a fault condition the fault current is carried to earth ground by the outer conductor.

Splicing High Voltage Cable

Splicing of high voltage electrical cables is required to maintain the electrical continuity of the conductor and shields and to maintain the insulation levels of the two electrical cables joined together. These cables are spliced by joining the two conductors: insulation is built up over the exposed conductor to provide insulation properties similar to those of the cable insulation: the cable shields are then joined to confine the electric field to the insulation.

In the case of PILC cable the built-up insulation material is an oil-impregnated paper. Due to presence of the oil a lead sleeve must be added over the PILC cable splice to hold the oil in and protect the insulation from the environment. This lead sleeve must be properly joined to the lead covering on both of the cables being spliced together to provide this environmental protection. The entire PILC cable splicing procedure requires not only a highly qualified cable splicer but a great deal of time.

Solid dielectric insulated cables are spliced in one of two ways: handwrapping with insulation tape or slipping a premolded cable splice over the joined conductors.

Handwrapping a splice by a highly skilled cable splicer requires almost as much time to complete as it does to splice PILC cable. The cable splicer must select the proper tape for each level of the splice, build up the tape to the proper dimensions for the cable being spliced, and insure that no air voids or contaminations are present in the final splice.

The premolded or slip-on cable splices for solid dielectric insulated cables were introduced in the 1950's. This type of cable splice is designed and manufactured at the factory to provide the insulation levels and electric field control required for a given size of electrical cable. The manufacturer is therefore able to test the insulation level and electric field control prior to shipping the unit. This type of cable splice can be installed in less than half the time required for a handwrapped cable splice, as shown in Table 2. Preparing the cable and joining the conductor are the same for either the premolded or the

handwrapped splices. However, once the cable is prepared and the conductors are joined, the premolded splice is slipped over the exposed conductors in less than 5 minutes. Therefore, the cable splicer requires much less experience to install a premolded cable splice than to install the other type of cable splice. This is important where cable splices are not installed frequently.

The cost, as shown in Table 2, of premolded cable splice material is much higher than material for the handwrapped tape of PILC splice, but this difference is offset by labor costs.

Premolded cable splices have proved to be highly reliable in the electrical utility company installations. Southern California Edison has installed approximately 217,000 premolded rubber components between May 1967 and December 1974 on polyethylene insulated cable. Of these 217,000 installations there have been 114 failures of 0.052% failure rate. Of these failures 103 were due to poor workmanship or incorrect application, one to a manufacturing defect, and 10 to unknown causes (insufficient material to determine cause).

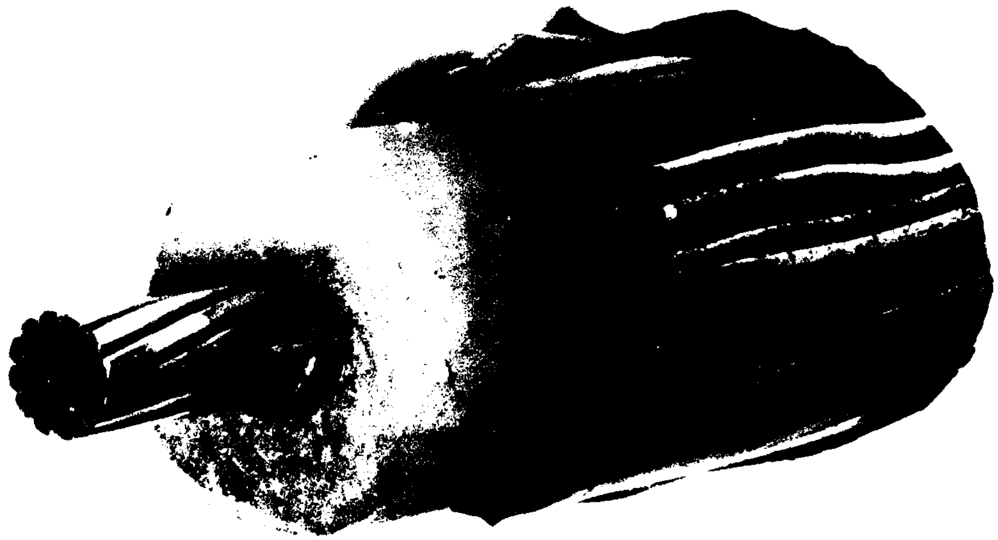

Figure 1. Cross section of cross-linked polyethylene-insulated underground cable.

Table 1. Cost of Cable Installation per 100 Feet of Length

Cable	Voltage (kV)	Conductor Size (MCM)	Conductor Material	Cost of Material ($)	Labor (man-hr)
3-1/C PILC	5	500	Copper	888	7.2
3/C PILC	5	500	Copper	844	3.7
3-1/C XLPE	5	750	Aluminum	301	3.5
3-1/C PILC	17	500	Copper	1,014	7.2
3/C PILC	17	500	Aluminum	1,032	3.7
3-1/C XLPE	17	750	Aluminum	437	3.5

Table 2. Splice Installation Costs

Splice Rating (kV)	Conductor Size (MCM)	No. of Conductors	Insulation	Splice Type	Labor (man-hr)	Material Cost ($)
5	750	1	XLPE	Tape	7.0	30
	750	1	XLPE	Premolded	2.9	78
	500	1	PILC	PILC	4.7	19
	500	3	PILC	PILC	13.5	43
17	750	1	XLPE	Tape	7.0	30
	750	1	XLPE	Premolded	2.0	99
	500	1	PILC	PILC	7.0	30
	500	3	PILC	PILC	17.0	66

TEST MATERIALS AND ASSEMBLY

Splice Kits

The following cable splice kits were procured for testing:

Manufacturer	Part No.	Voltage (kV)	Current (amperes)
Elastimold	25S	15	200
Elastimold	K25S	25	200
Elastimold	750-L2	35	600
Elastimold	650S	15	600
ITT* Blackburn	S-GAB-AM	15	400

*International Telephone and Telegraph.

Manufacturer	Part No.	Voltage (kV)	Current (amperes)
ITT Blackburn	SC-GH-AL	25	400
ITT Blackburn	S65	15	600
G.E.*	A1791717917	25	200
G.E.	SS-15-B	15	200
3M**	5718	15	200
3M	5402	15	150

Termination Kits

The following cable termination kits were procured for testing:

Manufacturer	Part No.	Voltage (kV)
Elastimold	35MSC	35
ITT Blackburn	SKC	25
ITT Blackburn	SKD	35
Raychem	HVT-O-B-2	15
G.E.	3T-15-B	15

High Voltage Cable

The high voltage cable used for the testing was aluminum-conductor, cross-linked, polyethylene-insulated cable (Figure 1). This cable has a conductor shield and a 30-mil insulation shield of conducting polyethylene. The cable has concentric copper outer conductors. The thickness of the cross-linked polyethylene insulation is: 175 mils for 15 kV cable, 260 mils for 25 kV cable, and 345 mils for 35 kV cable.

Assembly

Two 5-foot lengths of high voltage cable were cut and prepared, and cable splices were installed in accordance with the manufacturers' recommendations. The shields on the remaining ends of the cable were terminated with the appropriately sized stress-relief cones in accordance with the manufacturers' recommendations.

Figure 2 shows the resulting test items after assembly. Table 3 lists the types of cable splices, the type of stress-relief cones, and the size of the high voltage cable for each of the test items.

*General Electric.

**Minnesota Mining and Manufacturing.

Table 3. Components of Test Items

Sample	Splice		Cable		Stress Cones	
	Type	Manufacturer	(AWG) Size	Voltage (kv)	Type	Manufacturer
1	Premolded	ITT	3/0	15	Heat Shrink	Raychem
2	Premolded	ITT	3/0	15	Premolded	ITT
3	Premolded	ITT	3/0	15	Heat Shrink	Raychem
4	Premolded	Elastimold	3/0	15	Premolded	Elastimold
5	Premolded	Elastimold	3/0	15	Premolded	Elastimold
6	Premolded	G.E.	3/0	15	Taped	G.E.
7	Premolded	G.E.	3/0	15	Premolded	ITT
8	Taped	G.E.	3/0	15	Taped	G.E.
9	Taped	3M	3/0	15	Premolded	Elastimold
10	Taped	3M	3/0	15	Heat Shrink	Raychem
11	Premolded	3M	3/0	15	Premolded	Elastimold
12	Premolded	ITT	2/0	25	Premolded	ITT
13	Premolded	ITT	2/0	25	Premolded	ITT
14	Premolded	ITT	2/0	25	Premolded	Elastimold
15	Premolded	Elastimold	2/0	25	Premolded	Elastimold
16	Premolded	G.E.	2/0	25	Premolded	Elastimold
17	Premolded	G.E.	2/0	25	Premolded	Elastimold
18	Premolded	Elastimold	1/0	35	Premolded	Elastimold
19	Premolded	ITT	250 MCM	15	Premolded	Elastimold
20	Premolded	ITT	250 MCM	15	Premolded	Elastimold
21	Premolded	Elastimold	250 MCM	15	Premolded	Elastimold
22	Taped	G.E.	250 MCM	15	Premolded	Elastimold

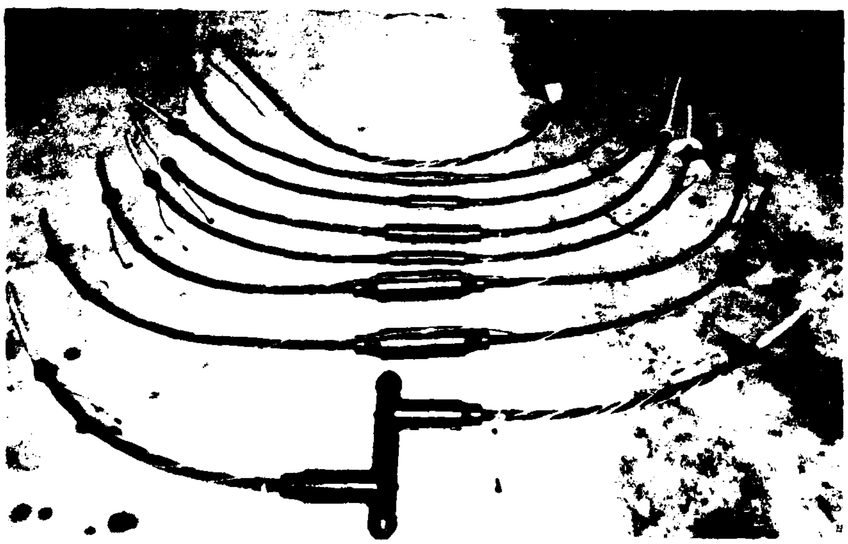

Figure 2. Cable splice and termination test items.

Testing Equipment

1. The Hipotronics, Inc., Model 7150-60 AC dielectric/insulation test equipment (Figure 3) was used to generate the adjustable high voltage 60-Hertz power. This unit has the following specifications:

(a) Input: 440 volts AC, 60 Hz, 145 amperes, 60 kV amperes

(b) Output: 150 kV AC at 0.4 amperes
75 kV AC at 0.8 amperes

(c) Distortion: Less than 5%

(d) Duty: 60 kV amperes for 1 hour
50 kV amperes continuous

(e) Voltmeter: 0-37.5/75/150 kV AC scale ±2% accuracy

(f) Current Meter: 0-1.0 amperes scale ±2% accuracy

2. The Hipotronics, Inc., Model CDO-68-C corona detector was used to measure the corona level.

3. The Multi-Amp Corporation, Model CB-150, circuit breaker test unit was used to generate the high current 60-Hertz power. This unit has the following specifications:

(a) Input: 208/220/480 volt, 60 Hertz, 15 kV amperes

(b) Output: 0-5,000 amperes at 0-3 volts
0-2,500 amperes at 0-6 volts
0-1,250 amperes at 0-12 volts

TEST PROCEDURES

Cable splices and terminations must provide at least the same level of protection as the original cable. The following tests were performed to compare the electrical and environmental characteristics of the cable splices and cable terminations to those specified by Insulated Power Cable Engineers Association (IPCEA) standard publications S-19-81 and S-66-524.*

The test items were connected to the dielectric/insulation test equipment (Figure 3). One end of the conductor was connected to the high voltage terminal, and the drain wire was grounded. The other end of the conductor was terminated in a toroid to eliminate corona produced by the sharp breaks in the conductor strands. The corona detector was connected to the high voltage terminal to monitor any high frequency voltage which would be caused by corona.

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*Insulated Power Cable Engineers Association. S-19-81 (Fifth Edition): Standard publication for rubber-insulated wire and cable. Belmont, MA, 1969.

Insulated Power Cable Engineers Association. S-66-524: Standard publication for cross-linked, thermosetting, polyethylene-insulated wire and cable. Belmont, MA, 1971.

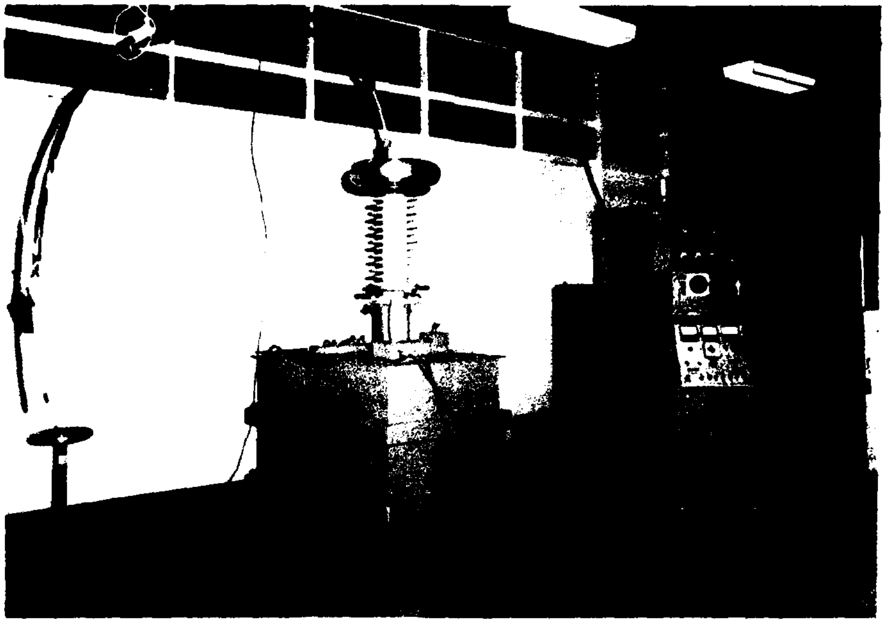

Figure 3. Equipment for testing dielectric insulation items.

The voltage on the high voltage terminal was slowly increased until corona occurred on the test item. The voltage was then reduced until the corona stopped. The voltage between the conductor and the drain wire of the test item was then recorded. This voltage is the corona extinction voltage.

The AC-withstand test was then performed. This consisted of subjecting the test item to a voltage of 35 kV for 15 kV test items, 42 kV for 25 kV test items, and 50 kV for 35 kV test items. This high voltage was maintained for a period of 1 minute.

At the end of the AC-withstand test the corona extinction voltage was again measured to determine if the test item had suffered any undetected damage.

The environmental test consisted of placing the test items in a tank of seawater (Figure 4). The conductors of each test item were connected in series and their insulation resistances were measured with a megger. A current equal to 140% of the current rating was supplied through the conductors of the test items. The current was cycled on for 75 minutes and off for 120 minutes, three times a day during working hours for 2 weeks. In this test the cable splice was heated internally and then allowed to cool down in seawater, approximating the field situation where most heating is internally generated.

After the test items were subjected to the environmental test, their corona extinction voltage was determined, and they were again subjected to the AC-withstand test.

TEST RESULTS

Table 4 gives the results of the laboratory testing of high voltage cable splices and termination.

All of the test items had corona extinction voltages higher than the operating voltage for which the items were designed.

All of the test items withstood the 1-minute application of high voltage except test item 1, which failed at one of the stress-relief cones. The failure, shown in Figure 5, was due to a puncture in the insulation caused by the concentrated electric field around a small air pocket located between the stress-relief cone and the insulation. The Appendix discusses the elastic field and termination of high voltage cable.

After the current-cycling test, two items failed. Test item 19 had a corona extinction voltage well above the minimum requirements for the voltage rating of the test item. During the AC-withstand test the insulation under one of the stress-relief cones was punctured as shown in Figure 6. This failure was due to a small cut in the insulation and the overheating of the insulation during the current-cycling test.

Table 4. Test Results

Sample	Corona Extinction Voltage (kV)	AC-Withstand Voltage (kV)	Current-Cycling Test: Current (amperes)	Current-Cycling Test: Number of Cycles	Final Corona Extinction Voltage (kV)	Final AC-Withstand Voltage (kV)
1	11.0	Failure[a]				
2	11.0	35	325	27	11.0	35
3	18.5	35	325	27	8.5	35
4	15.0	35	325	27	12.5	35
5	10.0	35	325	27	13.5	35
6	15.0	35	325	27	11.0	35
7	9.0	35	325	27	10.0	35
8	17.0	35	325	27	12.0	35
9	9.5	35	325	27	11.0	35
10	12.0	35	325	27	8.5	35
11	9.5	35	325	27	8.5	35
12	16.0	42	300	30	16.0	42
13	20.5	42	300	30	25.5	42
14	18.5	42	300	30	19.5	42
15	17.5	42	300	30	18.5	42
16	17.0	42	300	30	15.5	42
17	19.5	42	300	39	18.5	42
18	22.0	50	450	39	21.0	50
19	11.5	35	450	39	13.0	Failure[a]
20	14.0	35	450	39	15.5	35
21	20.0	35	450	39	15.0	35
22	16.0	35	450	39	1.5[b]	35

[a] Failure occurred in the insulation under one of the stress-relief cones while subjected to 35 kV during the AC-withstand test.

[b] The low value is due to the splice.

Figure 4. Test items submerged in salt water.

Figure 5. Failure of stress-relief cone on test item 1.

The second failure after the current-cycling test was test item 22. Its corona extinct voltage level was reduced to 1,500 volts, which is below the operating voltage of the cable splice. Figure 7 shows the splice of test item 22 after it had been cut in half. The test item insulation is discolored, indicating that the sample had been overheated during the current-cycling test. This overheating caused the tape used for the splice to melt and flow into the conductor strands. Some of the air from the conductor strands probably formed small air bubbles in the splice which would cause corona.

Figures 8 through 11 show the interior of cable splices without failures that had been subjected to current cycling while in saltwater. None of the samples show any signs of moisture entering the cable splice.

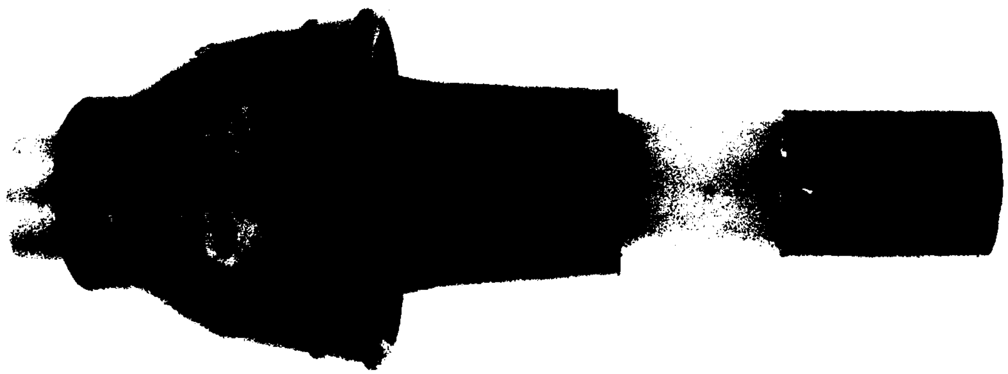

Figure 6. Failure of stress-relief cone on test item 19.

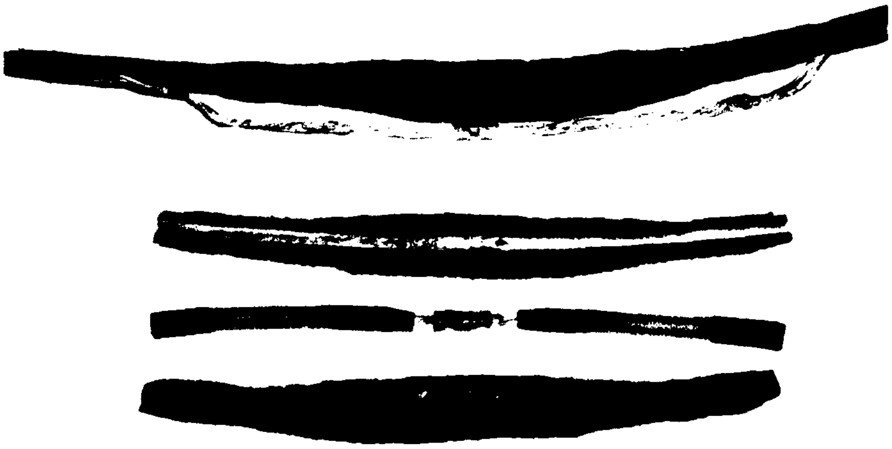

Figure 7. Cutaway view of cable splice on test item 22.

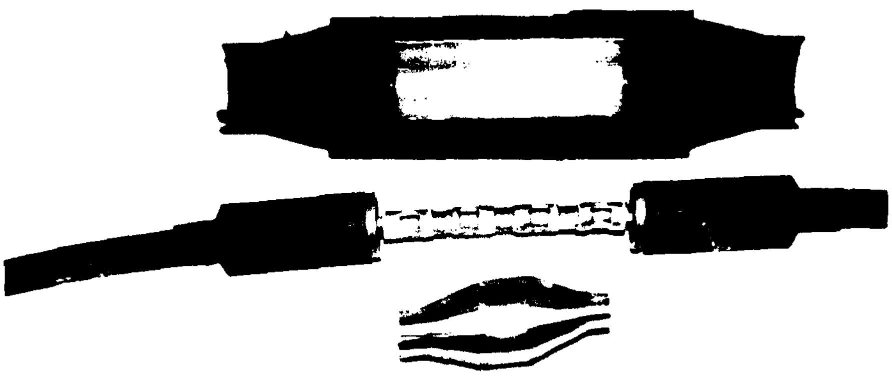

Figure 8. Cutaway view of Elastimold splice on 250 MCM cable after current-cycling test.

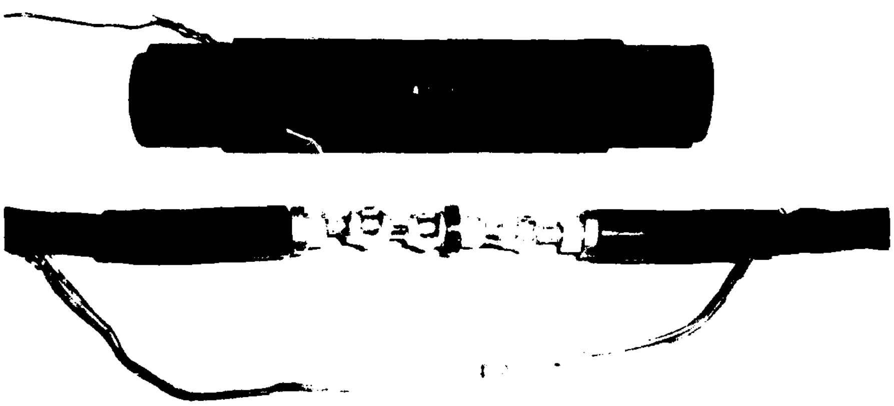

Figure 9. Disassembled ITT Blackburn cable splice after current-cycling test.

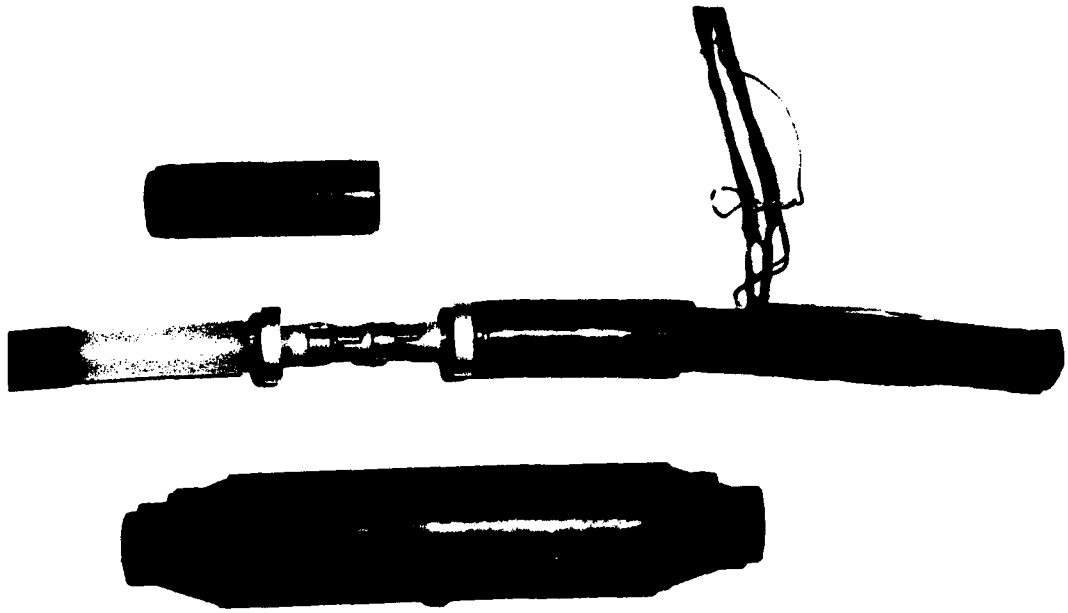

Figure 10. Disassembled 3M cable splice after current-cycling test.

Figure 11. Disassembled Elastimold 35 kV cable splice after current-cycling test.

CONCLUSIONS

The cable splicing and termination kits tested were simple to install for an electrician without prior cable splicing experience. Both premolded cable splices and handwrapped cable splices required the same careful cable preparation. After the cable was prepared, the premolded cable splices and terminations slipped on in a few minutes, while the handwrapped cable splices and terminations required a long tedious task of handwrapping with insulating and semiconducting tape. This additional task for handwrapped cable splices and terminations increases the chances for human error.

All of the samples tested gave a good watertight splice. There were no signs of moisture or salt in the cable splices when they were dissassembled after the testing. All the test samples had corona extinction voltages well above their designed operating voltages. The premolded cable splices are tested by the manufacturer to assure that all of the cable splices marketed have corona extinction levels above the designed operating voltage. This cannot be done with handwrapped cable splices, where the corona extinction level is determined by the skill of the cable splicer.

RECOMMENDATIONS

The premolded cable splices and cable terminations produce the highest quality with minimum training of the personnel installing the devices. This type of device should be used especially where the installing personnel do not perform frequent splices or in locations where rapid restoration of electrical service is required.

The premolded devices are designed for solid dielectric insulated cable of given dimensions. The cable size and insulation thickness at a given facility should be standardized wherever possible. However, if there are many different sizes of cable at a facility, different cable splices will be required for each size. This may make premolded cable splices uneconomical. However, this may be a minor problem because different sized cables can be spliced using only two premolded cable splice body sizes; cable dimension variations are taken care of with a cable adaptor. If several cable sizes are used, the appropriate cable adaptors can be purchased to handle any cable size while only purchasing the number of cable splice bodies required.

Appendix

DISCUSSION OF HIGH VOLTAGE CABLE TERMINATION

The electric field inside a cable with concentric conductors is:

$$E = \frac{V_a - V_b}{r \ Ln \ a/b}$$

where E is the electric field at a radius r

V_a is the voltage at radius a

V_b is the voltage at radius b

L_n is log base E

In the case of a 35 kV, 3/0, aluminum conductor cable, a = 0.279 inches and b = 0.624 inches. If a voltage of $35{,}000/\sqrt{3}$ volts is imposed on the conductors, the electric field next to the outer conductor is 40.2 volts/mil, and the electric field next to the center conductor is 90.0 volts/mil. The electric field that will break down air or cause corona is about 80 volts/mil. If the dielectric material was air instead of a solid dielectric, or if the solid dielectric contained air bubbles, the electric field next to the center conductor would be large enough to cause corona.

If the outer conductor (or shield) of the cable is abruptly terminated, the voltage distribution is radically modified as shown in Figure 12. Since $E = -\nabla V$ the electric field in Figure 12 is extremely high on the surface of the insulation next to the termination of the shield. The magnitude of the electric field is large enough to cause corona.

If a stress-relief cone is added to move the ground potential farther from the center conductor as in Figure 13, the magnitude of the electric field in the air is lower than the value required to cause corona.

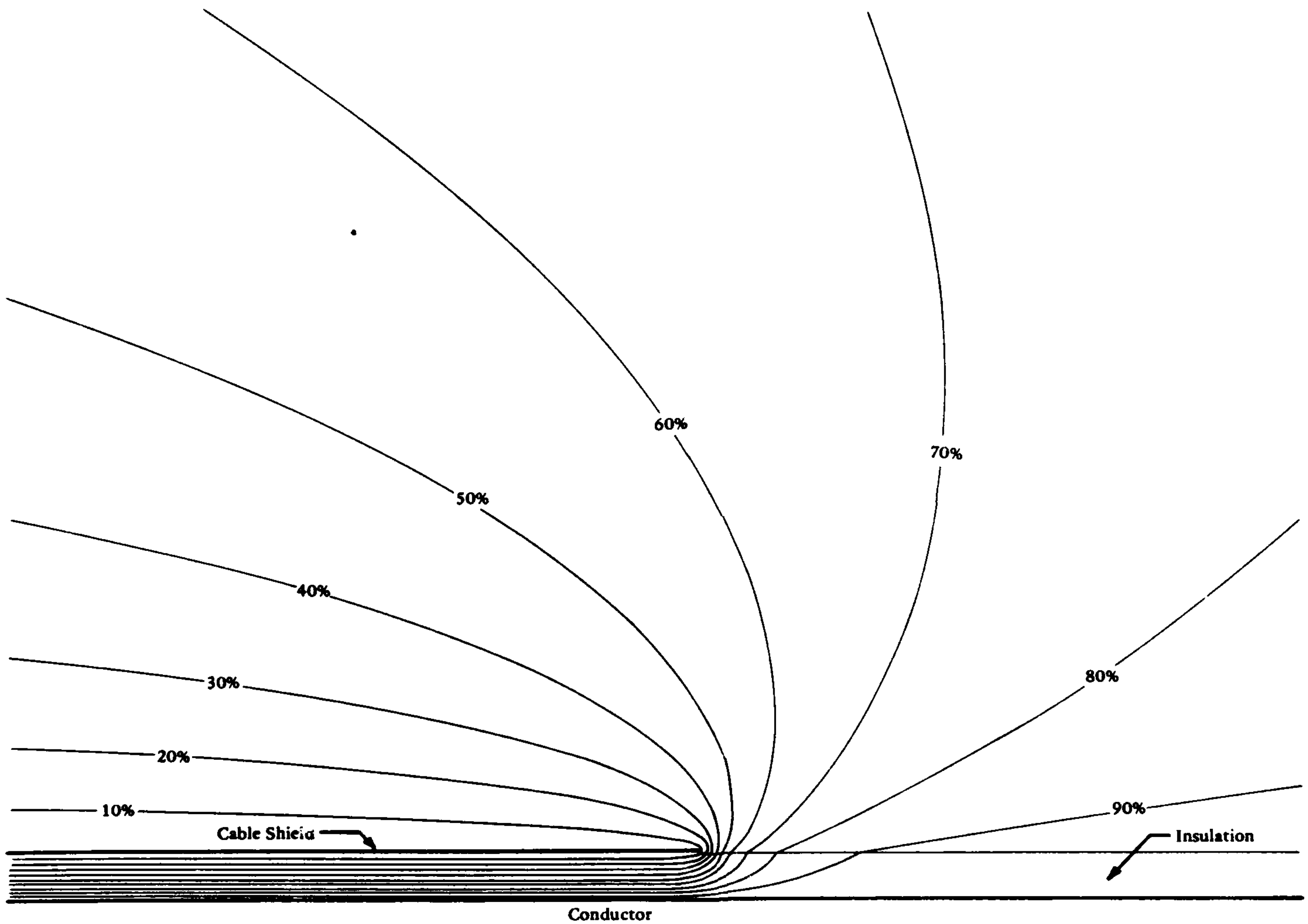

Figure 12. Computer plot of equal potential distribution with cable insulation shield abruptly terminated.

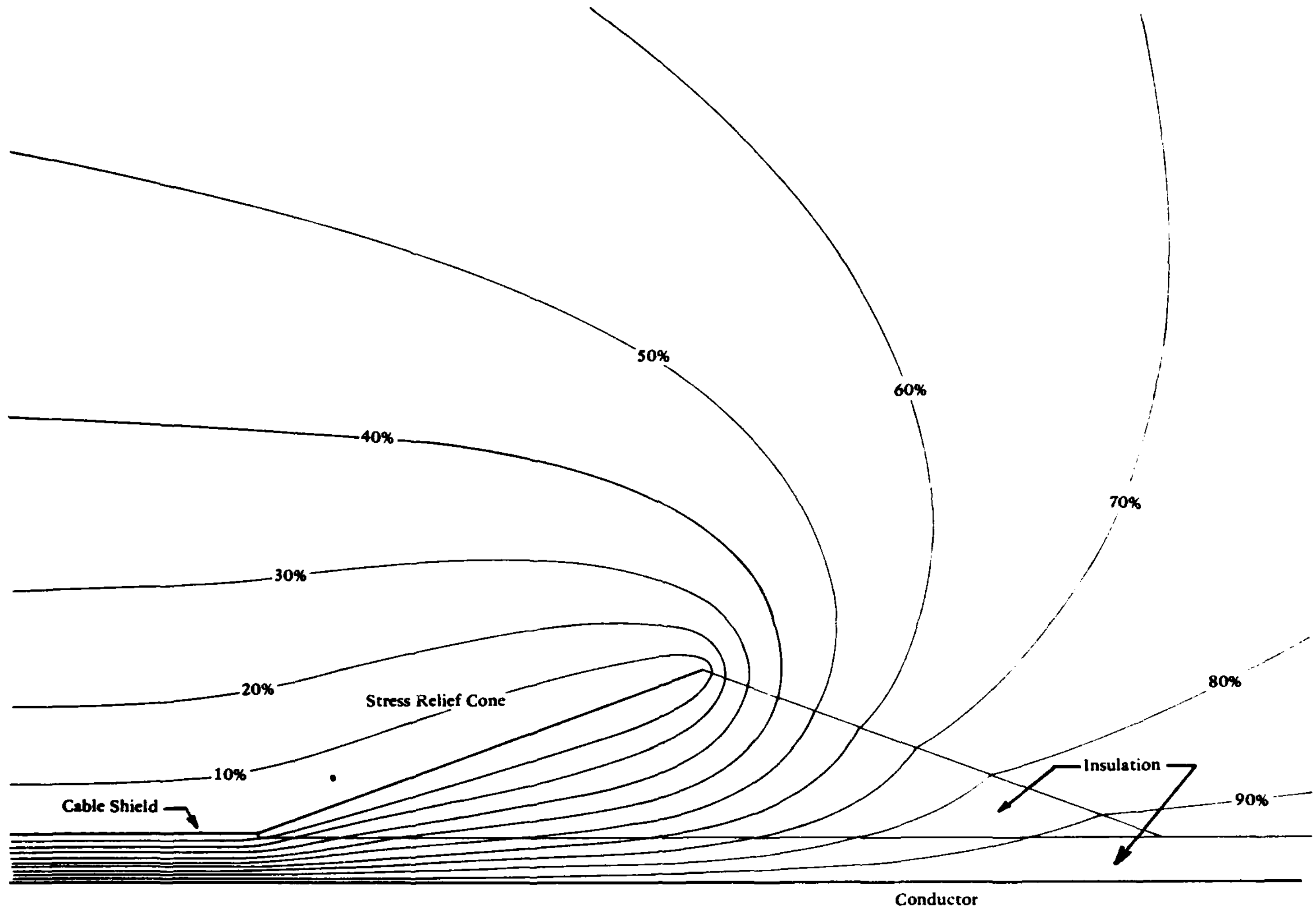

Figure 13. Computer plot of equal potential distribution with cable insulation shielf terminated into a stress-relief cone.

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